ROBUST TECHNIQUES FOR ESTIMATING PARAMETERS OF 3D BUILDING PRIMITIVES

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ABSTRACT

A semi-automatic building extraction system using two or more digitized overlapping aerial images has been enhanced by increased automation for the measurement of saddleback-roof (lopsided and symmetric) buildings, hip-roof buildings and flat-roof building (boxes). The goal is to minimize the interaction an operator has to do for measuring the form and pose parameters of 3D building models of the above mentioned types. The automated tasks are computed on-line and fully integrated in the work flow. Thus accepting or correcting the results or adapting the automated calculation is possible. The used methods are grey value correlation for absolute heights and the robust estimation techniques RANSAC and Clustering for the determination of heights and the other form parameters of the building primitives. These methods work on automatically extracted line segments. The automated modules have been empirically evaluated on more than 250 buildings in two datasets with different image quality and different densities of built-up areas. The results of these tests show a success rate of up to 88% for a form parameter estimation module and the height measurement.

1 MOTIVATION

A semi-automatic building extraction system using two or more overlapping aerial images based on the measurement of volumetric primitives [Englert and Gülch, 1996] has been migrated to an object oriented design [Gülch and Müller, 1997], enhanced by various automation tools and tested on large datasets [Gülch, 1997, Müller, 1997]. We can reach a gross time of about 70 sec per primitive using e.g. glueing, inheritance of parameters and a slider for structure height measurement instead of pointwise height measurement. A primitive can be a complete building model, like saddleback-roof or hip-roof building or a part of a building, depending on the image scale and the required level of detail. In order to increase efficiency, further automation is necessary. Since several years, we do have methods to measure the height of single primitives which require an already form adjusted model in one image, or methods to perform a final fine-tuning adjustment which requires very good approximate values. Having observed also difficulties on measuring the ground height (we currently assume a horizontal ground plane) caused by disturbances in the close vicinity of the buildings we had to develop new methods to overcome those problems. We have decided to determine also form parameters of the primitives, requiring only very few operations by the user, and adopted the classical way of measuring ground heights in the neighbourhood (if not inherited). The algorithms have to be fast enough (some seconds) to be applicable in this prototype system for on-line measurements. We can accept that time, if we otherwise need less manual operations. The goal for the newly developed automation is first of all directed to speed up the measurement process with a high success rate in sub-urban areas, with not too dense structures and an image scale in the order of 1:5000 to 1:15000. We do not regard this as too restrictive, as we can cover a very large amount of buildings in that way. The second restriction right now is on basic building types, like saddleback-roof buildings representing a large percentage of buildings or building aggregates. However, other primitives can be handled in exactly the same way, but we do not see an immediate need to implement them.

In chapter 2 we describe the basic methods developed for parameter estimation. In chapter 3 we describe the flow of operation for each of the primitives and in chapters 4 and 5 we present and discuss the results of empirical tests of the single modules on two datasets. We conclude with an outlook on further developments in this field.

2 METHODS FOR MATCHING AND PARAMETER ESTIMATION

2.1 Choosing Methods

The basic methods we use are a ground point and a roof-top point matching tool (for saddleback and hip-roof buildings) and robust estimation techniques to determine the other parameters that are not provided by the operator. The operator has to give only one or two points of the model and select one ground point in one image.

To automatically compute the absolute height of the top of a roof or of the ground we use cross-correlation on the grey values of the images with an epipolar search strategy [Müller, 1997]. This can be compared to classical point-transfer in Photogrammetry. For the roof-top height a point between the given roof-top points is automatically chosen and transferred to the other image(s). For determining the ground height the operator has to *select* a suitable point with good texture and without disturbing 3D objects in a small window around the point.

The remaining parameters are calculated by using extracted straight line segments as a basis. The line segments in each image are computed off-line and are loaded during the interaction for the part of the images where the actual measurement takes place. This process is fast enough due to the applied indexing and tiled storing of the line segments.

Given the model type and a set of unknown parameters the following search strategy must fulfill certain requirements. The used methods must be very robust because the number of outliers, (in this case defined as all image edges that do *not* belong to the searched building) can be very large (up to 90%). The search area itself, however, is reduced by the

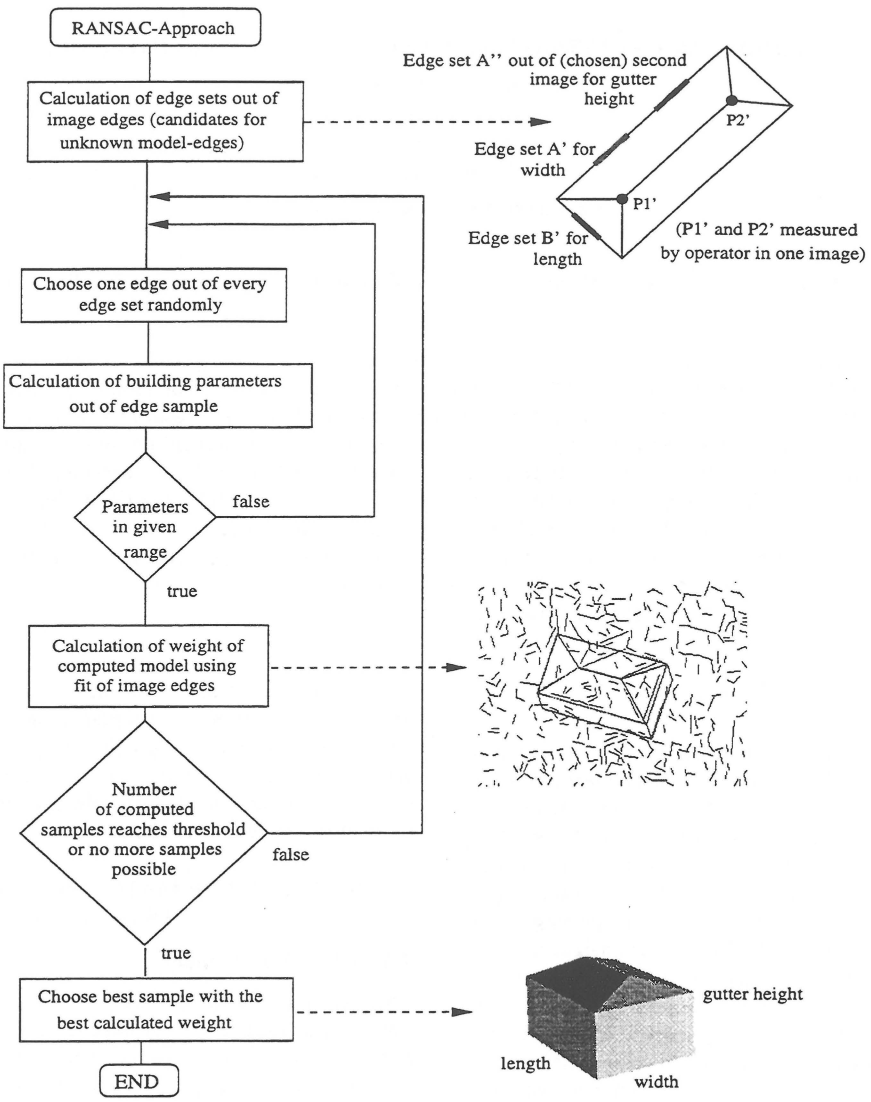


Figure 1: The RANSAC principle adapted to the parameter search for a hip-roof building.

given point(s) and a given range of the unknown parameters, depending on the expected building dimensions in the area. **R**andom **Sa**mple **C**onsensus (*RANSAC*) and *Clustering* are two strategies which are suitable to solve this task. Both methods have been implemented and evaluated, the Cluster method however only for the saddleback roof building.

2.2 The RANSAC Principle

RANSAC is in principle a simple algorithm which is able to find a solution for a set of unknown parameters out of a huge number of observations with many outliers [Förstner, 1989]. The procedure is as follows:

1. Choose a minimum set of u observations randomly.
2. Determine the unknown n parameters out of the observations.
3. Check the other observations regarding the residuals which occur when using the calculated solution of 2.
4. If the stopping criteria is not reached goto step 1.
5. Choose the best sample as a solution.

The minimum number of trials can be related to the expected amount e_i of erroneous observations [Förstner, 1991]. Suggesting a probability p for finding at least one set of good observations the number k of trials is:

$$k > \frac{\ln(1-p)}{\ln(1-\prod_{i=1}^{u}(1-e_i))} \qquad (1)$$

Figure 1 shows the algorithm adapted to the task of finding building parameters out of image edges. Here the example of a hip-roof building with unknown length, width and gutter height is chosen. In this case we need 3 image edges (=observations) for the calculation of the parameters. Only the edges in a certain area around the building are used. The candidates for the used image edges can be computed before the RANSAC loop starts. Here the constraints parallelism and orthogonality of image edges to the roof top are used.

In the RANSAC loop combinations of observations can be rejected because they would lead to impossible buildings, e.g an edge out of edge set B' is rejected as it is "left" of the

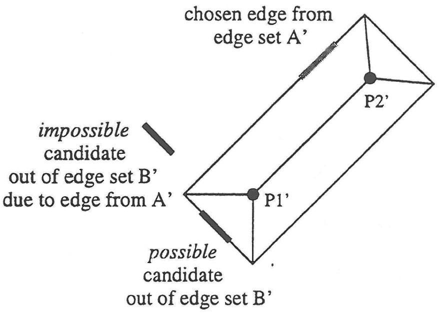


Figure 2: Example of possible and impossible combinations of edges.

chosen edge out of edge set A' (see Figure 2). These kinds of tests can already be done in 2D before 3D building parameters are computed. If the parameters are not in the given range they are rejected as well.

The next part of the algorithm uses image edges which are parallel to the model edges and near the model edges for the calculation of a weight. Here image edges of *all* patches (may be more than 2) are used. The weight of an observation is 0 (with the current weighting function) if the edge is not near a model edge. The length of the image edge is used as a weight in case of a match between model and image edge. Here it is possible to distinguish clearly between outliers and observations which support the given solution. That is the reason why in this case RANSAC can cope with a very large number of outliers (e.g. 90 %).

To leave the loop a threshold for the number of weighted samples is used. With this threshold one can control the computing time on one side and the success rate on the other side. Apart from the saddleback-roof building with only two parameters it is not favourable to calculate all combinations because then the algorithm would not be fast enough for an interaction environment with the currently used hardware.

2.3 Clustering

Another robust method to estimate parameters is *Clustering*. Clustering is highly recommendable for problems with few unknowns and a high redundancy [Förstner, 1989]. Within the algorithm a n-dimensional array is used where n is the number of unknown parameters. Every parameter has to be discretized. Therefore a finite parameter space is required and the result may be not accurate due to the discretization. Every value of the array is the weight for the special combination of parameters represented by the array indices.

While computing the result of the robust estimation every observation is taken into account. Every observation leads to a set of possible combinations of parameters which correspond to the observation. For these combinations the weight is increased. That is the reason why the array is called accumulator. In the most simple case the combination of parameters with the best weight is chosen as the solution.

2.4 Selection and Final Adjustment

We use Clustering for the calculation of the remaining two parameters of a saddleback-roof building only. To measure the other basic building types (i.e. hip-roofs, lopsided saddleback-roofs and boxes) are based on the RANSAC technique, because at least three parameters have to be calculated. For the acquisition of the saddleback-roof building the RANSAC algorithm has been implemented as well.

In each case a final robust adjustment of all parameters of the volumetric model in all images can further improve the overall result. This estimation procedure minimizes the difference of the image edges and the model edges. Also the parameters determined by the operator are adjusted. The method is adapted from [Schickler, 1992].

3 OPERATION FLOW

The operator has to perform in the best case three or four operations only for the basic building types which is less than in the case of classical photogrammetric point measurement. Two of the operations are simple *selections* and not *measurement* tasks.

3.1 Saddleback-roof Building

In the case of a *saddleback-roof building* four operations are needed: *select* the building type (saddleback), adjust the 3D model (primitive) of a saddleback to *two points* (two gable points) in one image, thus determining the rotation around the Z-axis, and the length of the building and finally *select* one ground point in the vicinity (in one image).

The system automatically determines the remaining **four** unknown parameters:

a) the absolute roof height,
b) the ground height,
c) the width of the building and
d) the gutter height.

The absolute roof height and the ground height are separately determined by the cross-correlation module. For the detection of the gutter height and the determination of the width of the building two modules are available:

- combination of Clustering and RANSAC: The cluster array is computed using only the line segments parallel to the roof-top edge. The best results of the cluster play the role of the "randomly" chosen samples in the RANSAC loop. Therefore the weights of only a few number of samples have to be calculated.
- RANSAC: Two edges which are parallel to the roof-top are chosen as a sample (Figure 3). One edge belongs to the left image and one to the right. Due to the given range of the gutter height and the width many combinations can be rejected. For *all* suitable combinations the weight of the sample is computed as described above.

Figure 6 shows an example for an operation flow for the saddleback-roof building.

3.2 Lop-sided Saddleback-roof Building

The general operation-flow for the lop-sided saddleback-roof building is similar to the symmetric saddleback-roof building. The absolute roof height and the ground height are separately determined by the cross-correlation module, and the remaining parameters are computed by the RANSAC technique. The difference is that the lop-sided saddleback-roof building has one additional parameter (or **five** unknown parameters): Because of the missing symmetry of the roof-top two widths

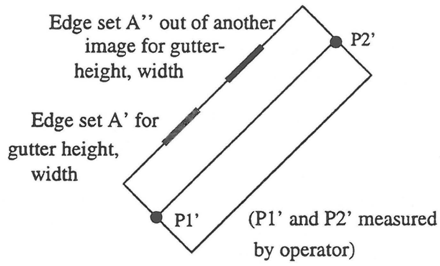


Figure 3: Saddleback-roof building - edge sets used for the RANSAC algorithm.

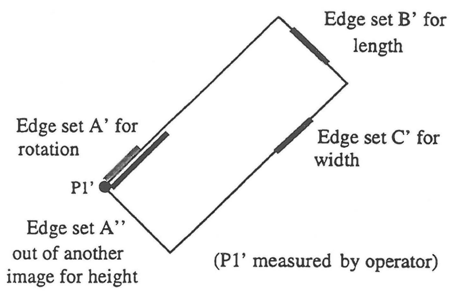


Figure 5: Box - edge sets used for the RANSAC algorithm.

have to be calculated. So Clustering is not suitable, because now three unknown parameters (width 1, width 2, height of the gutter) have to be determined. Two edges on both sides of the roof-top in the left image and one edge in the right image are the samples used in the RANSAC algorithm (see Figure 4).

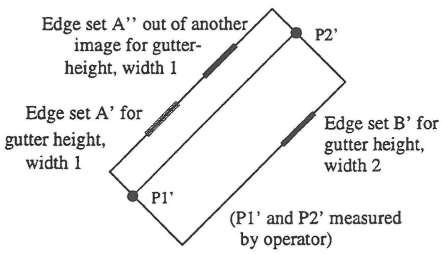


Figure 4: Lopsided saddleback-roof building - edge sets used for the RANSAC algorithm.

3.3 Hip-roof Building

In the case of a *hip-roof building* the operator performs practically the same operations: select the building type (hip-roof), adjust the 3D model (primitive) to two points (two roof top points) in one image, thus determining the rotation around the Z-axis, and the length of the roof top and finally selects one ground point in the vicinity (in one image) and the system automatically determines the remaining **five** unknown parameters:

a) the absolute height of the roof top,
b) the ground height,
c) the length of the building,
d) the width of the building, and
e) the gutter height.

The search for length, width and gutter height is performed applying the RANSAC technique. The edge sets used within this search are already mentioned in Figure 1.

3.4 Flat-roof Building (Box)

In the case of a *box*, even less parameters have to be given: the operator selects the building type (box), adjusts one specific point of the 3D model (1 corner point on the top) in one image, and finally selects one ground point in the vicinity (in one image) and the system automatically determines the remaining **five** unknown parameters:

a) the absolute height of the flat roof,
b) the ground height,
c) the length of the building,
d) the width of the building and
e) the rotation around the Z-axis.

The search for all parameters except the ground height is in this case performed applying the RANSAC technique (see Figure 5 for the used edge sets).

3.5 System Design Remarks

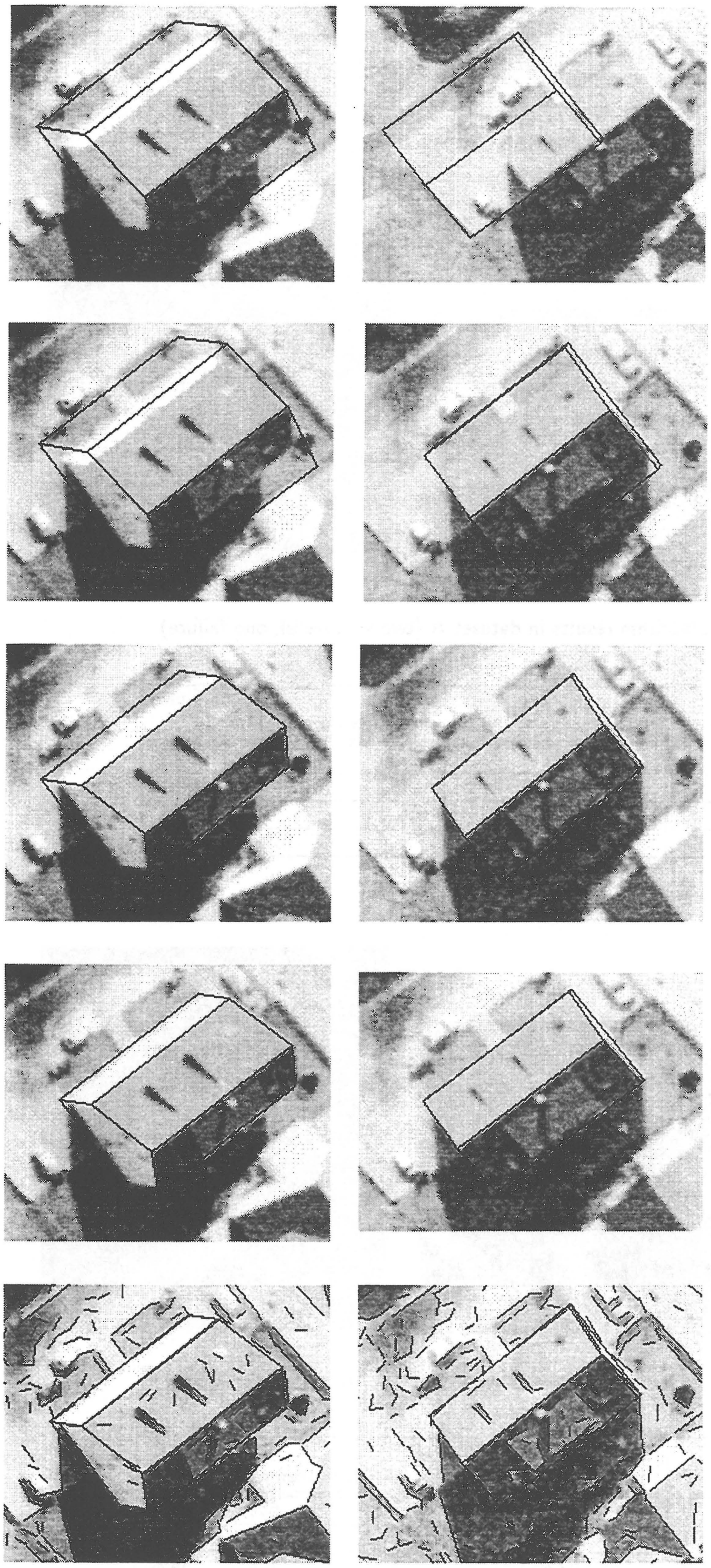
Because many steps of the RANSAC method are identical for different model types, the inheritance-feature of an object oriented design is very suitable to minimize the extra code which has to be written for every model type. This design is based on the "Template Method" described in [Gamma et al., 1995]. In a super class all the methods which do not depend on a specific model type are put together. The specializations consist of the strategy for choosing the image edges for a sample and the determination of the building parameters out of this set of observations. The weighting procedure and the RANSAC loop is identical for every model type. Due to this fact, we favor the RANSAC procedure also for the saddleback-roof building even if the Clustering yields to comparable results.

4 EMPIRICAL TESTS

All modules are investigated concerning their success rate. We distinguish between a) full success without any further intervention by the operator, b) one ore two additional attempts or c) failure, which requires a more or less complete correction and manual adjustment by the operator. In case of a failure, however, only one or two manual interactions can be enough to trigger an automatic final determination of the remaining unknown parameters.

4.1 Datasets

We have started to examine the ground point and roof-top point matching tools as well as the estimation of form parameters for saddleback-roof, hip-roof and flat-roof buildings on two different datasets. The first dataset A consists of a pair of two aerial images with moderate to good image quality. Within the second dataset B (from the project described in [Läbe and Ellenbeck, 1996]) we use image patches of the buildings to be measured. For every building 6 image patches exist. As Figures 7 and 8 show the image quality from dataset B is considerably lower than the one of the image pair (A). In both datasets the image scale is 1:12500.



Operator measures two gable points in the left image.

Automatic roof-top height (cf. right image).

Automatic gutter matching (computation of width and height).

Automatic ground height (Please note: the roof is overhanging which makes manual adjustment difficult).

Fine adjustment and result (the automatically extracted edge segments are visualized as well).

Figure 6: Example of measuring a saddleback-roof building with the developed automatic tools (Single measuring steps (top-down) in both left and right images).

Saddleback		Hip-Roof			Box	
height of gutter	width of building	height of gutter	$(length - \overline{P_1'P_2'})/2$	width of building	absolute height (dataset A)	length/width
0.5-15m	6-40m	1-10m	1-10m	4-30m	50-180m	3-50m

Table 1: Parameter ranges for RANSAC-Approach.

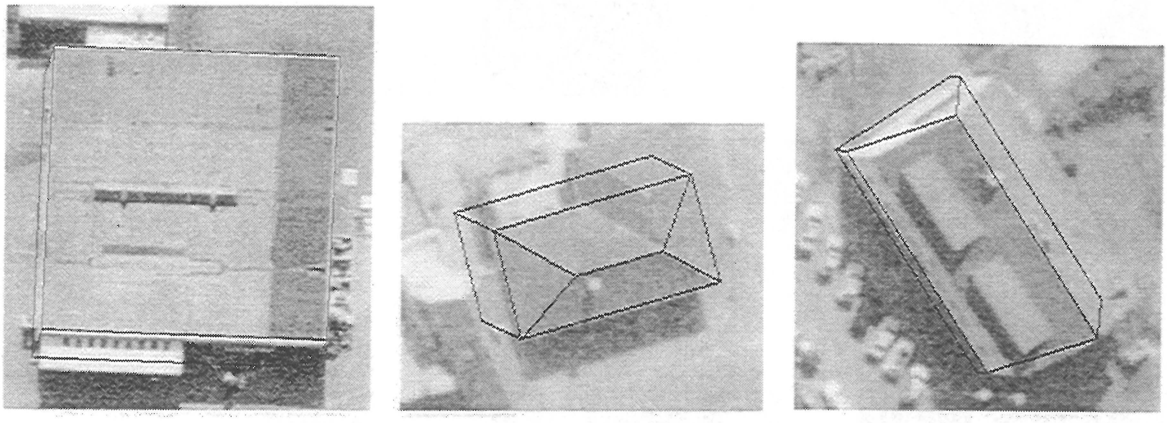


Figure 7: Examples for RANSAC algorithm results in dataset A (two successful, one failure).

Model type	Number	Success 1st attempt	2nd attempt	3rd attempt	Failure
Saddleback (RANSAC)	30	80%	0%	0%	20%
Saddleback (Clustering)	30	43%	20%	7%	30%
Hip-Roof (RANSAC)	17	76%	6%	6%	12%
Box (RANSAC)	30	23%	7%	13%	57%

Table 2: Success rates for dataset A (image pair).

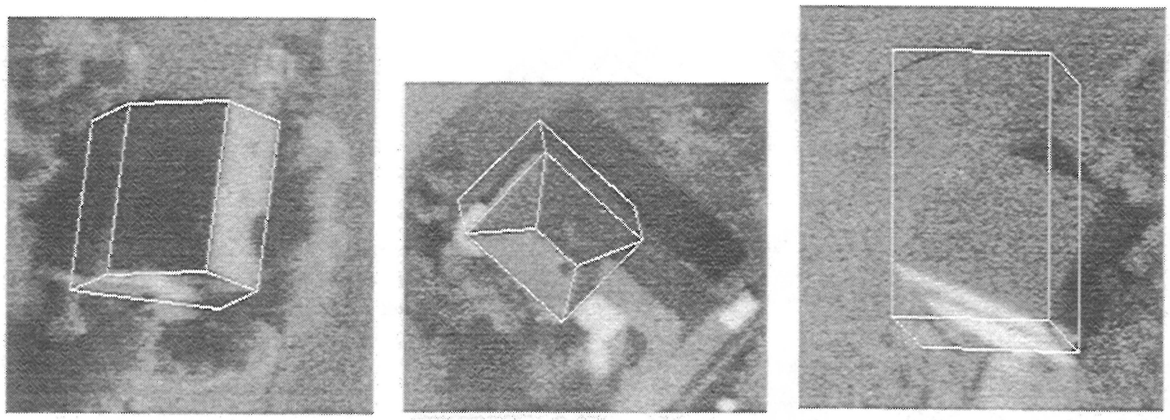


Figure 8: Examples for RANSAC algorithm results in dataset B (two successful, one failure).

Model type	Number	Success 1st attempt	2nd attempt	3rd attempt	Failure
Saddleback (RANSAC)	50	46%	8%	6%	40%
Saddleback (Clustering)	50	58%	16%	0%	26%
Hip-Roof (RANSAC)	29	52%	7%	7%	34%
Box (RANSAC)	25	8 %	12%	4%	76%

Table 3: Success rates for dataset B (6 image patches).

Dataset A is scanned with 12.5μm, dataset B with 11μm pixel size. So the ground resolution is comparable.

In both datasets the density of buildings is moderate. There is enough space nearby to select a suitable ground point. The buildings are of different size ranging from about 75m^2 to more than 500m^2; there are single buildings or buildings connected to others. Some buildings have disturbances and they are partly surrounded by bushes and trees. There have been measured parts of complex buildings as well. No approximate values for the unknown parameters were used, but we define a certain range for the parameters for the RANSAC approach. Table 1 shows these ranges for the different model types. We have decided to work in object space units for higher flexibility and better understanding. We have chosen slightly different ranges for the different building types to be able to check the influence. The values are the same for all examined buildings in all datasets except the absolute roof height in case of a box which is set different in the two datasets. But the setting of this parameter is not very critical, as the range is usually known from the flight plan, but of course the setting influences the performance of the parameter estimation.

4.2 Correlation

The test for the correlation procedure has been performed on the roof-top and on ground points separately on saddleback and hip-roof buildings in both datasets. In the case of a roof-top we use only 1 trial as the point is chosen *automatically* between the two given precisely located roof-top points. In case of failure the operator measures the height manually.

In the case of the ground point several trials are possible because the success depends on the "intelligent" choice of the point. Table 4 shows the results of some tests for the correlation to find absolute heights.

Trials roof-top	Success	Trials ground	Success
109	87%	30	83%

Table 4: Success rates for correlation to find absolute heights.

4.3 RANSAC and Clustering

Tables 2 and 3 show the results of the tests we established for the RANSAC and the Clustering approaches with the datasets A and B. For the second and third attempt the operator could change the used images and/or in case of a box select another corner point. Some examples of successful and false determination of the parameters computed by the RANSAC algorithm in both datasets are shown in Figures 7 and 8.

4.4 Overall Performance

In the dataset A we examined the determination of all **four** unknown parameters (roof height, ground height, gutter width and height) of each of the 30 *saddleback-roof* buildings (cf. Table 2) but without the final adjustment step. 10 of the buildings were correctly adjusted in the first attempt, 8 buildings required the manual adjustment of 1 parameter only. For 11 buildings we applied the Clustering procedure between 1 and 3 times and we finally needed to adjust between 1 and 3 parameters manually. For one building the procedure didn't work at all (cf. saddleback-roof building in Fig. 7). For the 20 successfull attempts a gross time of 41 seconds per building was reached.

With the same image material we tested the overall procedure (without fine-adjustment) to determine all **five** parameters (roof height, ground height, gutter length, width and height) of 10 *hip-roof* buildings. The results show an even better behavior: 6 of the buildings were correctly measured with 1 attempt only, for the remaining 4 buildings, we had to correct 1 parameter (the gutter width) and once to choose another ground point.

5 DISCUSSION

Correlation. The first automatic task to discuss is the correlation for finding absolute heights. For the *roof-tops* it works well (cf. Table 4) as long there are no big disturbances due to e.g. chimneys right on the roof top.

For the robustness of the *ground height* determination more investigations may be necessary. Here big differences between unexperienced (not documented here) and experienced operators can be observed. The high success rate for the ground points in Table 4 is mostly due to the skills of that operator in selecting a "good" point.

Here two possibilities to improve the success rate can be mentioned: On one hand side training of the operator. The success depends on the operator skills to define the point with which the correlation is computed. There must be enough texture and no 3D disturbances around that point. On the other hand side, another or an adapted algorithm for that task could be developed. We expect improvements by e.g. an automatic setting of window sizes, or a feature based approach, based on a complete image segmentation [Fuchs and Förstner, 1995] instead of grey value correlation.

Robust Techniques. The results for the saddleback-roof and the hip-roof buildings are extremely promising, whereas the calculation of the parameters of the box is problematic. The performance for the lop-sided saddleback-roof (not documented here) is expected to be similar to the saddleback-roof and the hip-roof buildings.

We can see from the results in dataset A (Table 2) and dataset B (Table 3) that the influence of a lower image quality can not be compensated by a higher amount of image patches.

For the *saddleback-roof building* we compare the Clustering and the RANSAC methods. In dataset A the success rate for the RANSAC method is about 10% higher than for the Clustering, whereas in dataset B it is about opposite. In the case of RANSAC the samples are actually chosen from two images only (for the weighting of course from all images), which could explain the superior performance of Clustering in dataset B, where edges from all 6 images are taken into consideration. Using the RANSAC approach we can further see that additional attempts by changing the image used to select the samples improve the results. Please note that in dataset A the RANSAC procedure checks all possible samples and no changes of images had been applied, whereas in dataset B other images had been chosen in the second and third attempt. Using the Clustering additional attempts are possible, when changing the approximate values of the parameters.

The better performance of the *hip-roof buildings* in dataset A compared to dataset B is most probably due to the higher image quality. Even if we have to estimate one parameter more for the hip-roof building compared to the saddleback-roof building we get a comparable or even better performance, as we have chosen slightly more restrictive parameter ranges for the hip-roof building (cf. Table 1).

The current algorithm for finding the parameters of the *box* has additional problems. The operator gives one corner point only and the computer has to find edges which begin at this corner and belong to the roof of the box. Using a normal edge extraction it is clear that extracted line segments are not connected to the corner point itself. So the search area around the point has to be large which leads to more false image edges. Often short image edges which are near a corner point are the reason for a bad estimation of the rotation around the Z-axis. Then the other parameters of the box can not be computed either correctly. The box in Figure 8 (right) can serve as an example for failure of that type. A solution would be to give an edge instead of a corner point as a start information, which would not increase the amount of operations for the user.

Tables 2 and 3 show that the amount of successful second and third attempts for the box is very large compared to the number of successful first attempts. This is a hint for a too low threshold for the number of samples computed in the RANSAC loop according to equation (1). This means we had assumed a too low number of outliers. We are expecting a significant higher success rate for the first attempt when we increase this threshold. On the other hand side of course the computation time for *all* boxes will be longer.

Our tests show that for all robust tasks missing edges of the buildings are more difficult to handle than many "outlier edges" which do not belong to the building.

Overall performance. The results of combining procedures are promising as well, with slightly better results for the hip-roof building in the few cases examined. A general problem for the height determination either by correlation or the robust techniques are image edges which are parallel to the epipolar lines. In those cases we currently require operator assistance and manual measurement.

The question of operator strategy is still open. When the first automatic attempt fails the operator must decide if he tries the automatic procedure again or if he adapts the missing parameters manually. It is as well a compromise between computation times and time for manual adjustment. If the selected model does not fit well to reality the result will be some kind of generalization, which means the operator has to accept it or choose the proper model instead.

6 CONCLUSIONS

We have presented methods for robust estimation of pose and form parameters of volumetric building models from digital imagery. Our evaluations on more than 250 buildings show that the strategy to support the operator with automated tools which work on-line is feasible. From the psychological point of view we believe it is a better way to introduce automation than letting the operator only to correct the results calculated off-line by the computer. Due to the integration in an interaction environment the algorithms can be used and tested even if the success rate (up to 88%) has no yet reached a status which can be described as "works in nearly all cases".

For the saddleback-roof and hip-roof buildings the results of the tests fulfill our expectations. For the box the search strategy should be changed. For this building type the minimum number of parameters which the operator has to give (one point in one image) has already been reached. For the saddleback-roof and hip-roof buildings the possibility to reduce the operator action to the measurement of one point exists. But here investigations and adaptations should first be done for increasing the stability and performance of the already solved tasks, before further minimizing the operator actions. To generally increase the success rates for the robust techniques more information sources than only image edges may be necessary. Here techniques which are using a complete image description, i.e. extracted lines, points and blobs [Fuchs and Förstner, 1995] are most promising.

We think that our investigations lead to an increased performance in semi-automated building extraction, which would mean a further milestone towards practical acceptance.

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